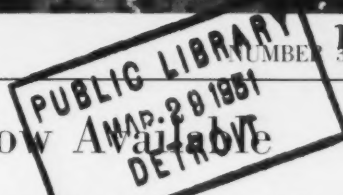# National Bureau of Standards

TECHNICAL NEWS BULLETIN

Atomic Standards of Length Now Available

The availability to science and industry of an ultimate standard of length was announced recently by the National Bureau of Standards and the Atomic Energy Commission. The standards consist of spectroscopic lamps containing a single pure isotope of mercury. These lamps enable any research organization that has the auxiliary optical equipment to have for the first time an ultimate primary standard of length in its own laboratories.

Distribution of the lamps will be handled by the National Bureau of Standards. They will be available to qualified government, industrial, and educational laboratories both in this country and abroad, engaged in precision length measurements and related research. All requests for information and applications should be addressed to the Coordinator of Atomic Energy Commission Projects at the National Bureau of Standards, Washington 25, D. C.

The NBS-Meggers Mercury 198 Lamps, prepared under the direction of Dr. W. F. Meggers, Chief of the National Bureau of Standards Spectroscopy Laboratory, contain about 1 milligram of mercury of atomic weight 198. Mercury 198 is obtained by the transmutation of gold in a nuclear chain-reacting pile. In 1931, Dr. Meggers suggested that an ultimate standard of length could be obtained if one of the even atomic weight isotopes of mercury could be isolated from the seven that occur all mixed together in natural mercury. At that time no means existed for obtaining useful amounts of a single isotope. In 1945, following the war-time development of the nuclear pile, the production of a useful quantity of artificial mercury 198 was achieved at Oak Ridge by subjecting pure gold to intense neutron bombardment.

Mercury 198 is sealed in a small glass tube and caused to glow brightly by the application of high-frequency radio waves. The light waves emitted by the single isotope have extremely sharply defined wavelengths that can be used for length measurements of great precision. These particular waves are uniquely characteristic of the mercury and remain unaltered with time.

The new standard of length is based upon the wavelength of the green light emitted by the lamp. This wavelength, near 21 millionths of an inch, is consistently emitted with a reproducibility greater than one part in a billion. Length measurements based upon it can readily be made with an accuracy of one part in 100 million. New apparatus now under construction at this Bureau is expected to extend the accuracy to one part in a billion.

The measurement of length in terms of a characteristic radiation from a particular atom involves the optical technique of interferometry whereby the separation of two precisely flat plates is measured in terms of the number of wavelengths of light contained in the distance between them. Because the number of waves contained in any practical distance is determinable without error and because the wavelength of the light from a single, pure isotope of even atomic weight is so sharply defined, accuracies of measurement heretofore impossible can be obtained.
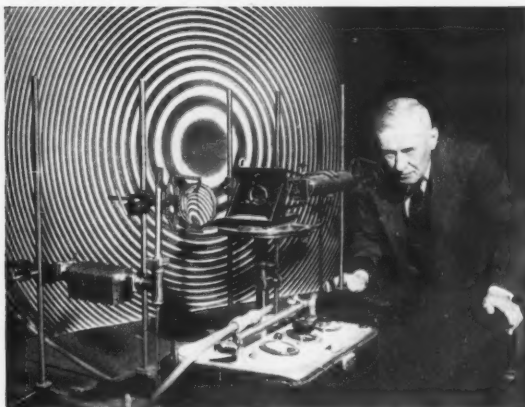
Dr. Wm. F. Meggers positions the eyepiece of the optical train prior to observation of the circular interference fringes of green light from the electrodeless Hg^{198} lamp (left foreground). Length measurements based on this interference pattern (background) can be made with an accuracy of 1 part in 100 million.

Although the world's official primary standard of length is still the distance between two lines on a metal bar, practically all precise measurements of length in the twentieth century have been made and will continue to be made with light waves. When accuracy greater than the part in 10 million possible with the standard meter is necessary, only the new spectroscopic standard meets the need.

Up to the present time the wavelength of the red light from cadmium has been used as a wavelength standard. In 1927 the International Conference of Weights and Measures provisionally adopted the value 1,553,163.13 wavelengths of cadmium red radiation as equal to 1 meter. In 1948 the NBS proposed that the meter be defined in terms of the radiation from mercury 198. This is now under consideration. Present measurements show that 1,831,249.21 wavelengths of the green radiation from mercury 198 equals 1 meter.

The fundamental advantage of mercury over cadmium is that the wavelengths of the light from mercury are much more sharply defined. Cadmium consists of six principal isotopes, which are not separated. They emit light of slightly different wavelengths. When length measurements are made with light having this mixture of wavelengths, a region of confusion results that limits the accuracy. Mercury has other advantages: (1) the atoms are heavier, move about more slowly, and hence disturb the wavelength less; and (2) the light can be obtained without heating the mercury to a high temperature and thereby speeding up the atomic motion. When all the advantages are considered, it is found that the mercury 198 provides a stand-

Hg^{198} lamps, produced in the NBS spectroscopy laboratory, enable any research organization to have a superior standard of wavelength in its own laboratories. Here, F. Oliver Westfall is sealing off a lamp after it has been evacuated, and a measured amount of argon and pure mercury^{198} admitted.

Contents

ard 300 percent more accurate than cadmium. The life of the NBS–Meggers 198 Lamps appears to be infinite; a lamp under continuous excitation since October 1949—over 10,000 hours—has shown no significant deterioration.

Recently the Oak Ridge Laboratories of the Atomic Energy Commission have succeeded in isolating practical quantities of mercury 202 by magnetic separation methods. The advantages of this isotope over the 198
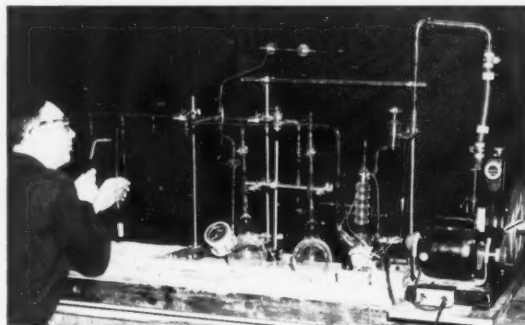
isotope are negligible except for certain important problems in atomic research. Mercury 202 lamps, if needed for research in atomic physics, can also be obtained from the National Bureau of Standards by special arrangement. The wavelength of the light from the 202 isotope has not as yet been accurately measured, and hence the information needed for its use as an atomic length standard is not available.

NOTE: For further technical details see, Light wave of Mercury 198 as ultimate standard of length, NBS Technical News Bulletin **31**, 133 (Dec. 1947); also Lamps and wavelengths of mercury 198 by W. F. Meggers and F. O. Westfall, J. Research NBS **44**, 447 (1950) RP2091.

Ceramics in Nuclear Physics

The use of ceramics, or metal-ceramic combinations, offers the only practical alternative to the use of metals for shields, moderators, fuel rods, and coatings in atomic piles designed to operate at temperatures in excess of about 1,000° C. In the light of present knowledge, many difficult and complex problems remain to be solved. These problems range from the mass fabrication of parts and the application of continuous protective coatings, to the development of additional fundamental data on the ceramic materials themselves and on the phase relations of the systems involved.

The need for information in this field prompted the Atomic Energy Commission to establish a project at the National Bureau of Standards directed toward the compilation and analysis of data presently available at the Bureau and in other laboratories on ceramics in nuclear physics. Prepared by R. F. Geller of the NBS porcelain and pottery laboratory, the survey (see note) presents the physical and nuclear properties of 24 ceramic materials of interest to the nuclear physicist or engineer; 15 of these materials are oxides, while 9 are carbides.

Ceramic shapes for this application are, almost without exception, mixtures rather than pure compounds. The purpose of such mixtures is the same as for metallic alloys. Certain desirable or necessary properties may not be obtained with the pure compound but can be developed by addition of one or more other materials. The addition of carbon to iron to produce steel is a classic example of a metallic alloy. Likewise, in ceramics, feldspar is added to kaolin to obtain the strength and translucency of china for tableware.

The nuclear properties of the ceramic mixture must also be considered when the ceramic is intended for service involving neutron bombardment or subjection to fission fragments. An illustration is the common ceramic glaze that usually contains boron, introduced as borax or as boric acid. So far as ceramic considerations are concerned, there is no objection to boron. However, this element has a powerful influence on the capture cross section. A ceramic shape assigned for use as a moderator would therefore be quite unacceptable if it contained even a thousandth of 1 percent of boron.

The nuclear properties that determine the probable suitability of a ceramic composition for pile construction are capture (or absorption) cross section, scattering cross section, and slowing-down power. These terms refer to the ability of the material to absorb, scatter, or retard neutrons when it is placed in the path of a neutron beam. An additional property of ceramics that is of value in some applications, particularly as the moderator in thermal piles, is low atomic weight.

As a result of this survey, a comprehensive tabulation (see note) of properties has been prepared. Oxides and carbides of beryllium, hafnium, silicon, titanium, and zirconium; the oxides of aluminum, barium, calcium, cerium, chromium (chromic), cobalt (cobaltous), lanthanum, magnesium, and niobium; and the carbides of boron, tantalum, uranium, and wolfram are included. Properties of six pure elements round out the data: aluminum, beryllium, boron, cadmium, carbon (graphite), and zirconium.

In addition to the nuclear properties, the more important physical characteristics are given. These include scatter and absorption cross sections, slowing down power, density, thermal expansion and conductivity, elastic modulus, strength in bending, and melting point.

NOTE: For further technical details, see A survey of ceramics for nuclear reactors, by R. F. Geller, Nucleonics 7, No. 4, 3 (1950).

Two New Elements Confirmed

Recent spectroscopic investigations by W. F. Meggers, B. F. Scribner, and W. R. Bozman of the Bureau give positive identification of two new artificial elements. Not found in nature, the elements—known as technetium (Tc) and promethium (Pm)—are byproducts of uranium fission. They were supplied by the Atomic Energy Commission. Studies at the Bureau of the first optical spectra of these elements have revealed by analysis and interpretation many properties of the atoms and of their nuclei. They have also provided reliable wavelengths and intensity data for about 5,000 new spectral lines, the strongest of which are at least one thousand times more sensitive than their X-ray spectra. This work gives new impetus to a more extensive search for the elusive elements in natural sources.

For many years these two predicted chemical elements were vainly sought in nature. One was predicted in 1869 by Mendeleev, whose observation that chemical valencies were periodic functions of atomic weight led him to affirm that a chemical homolog of manganese was unknown. The other was predicted in 1902 by Brauner, who pointed out that the atomic
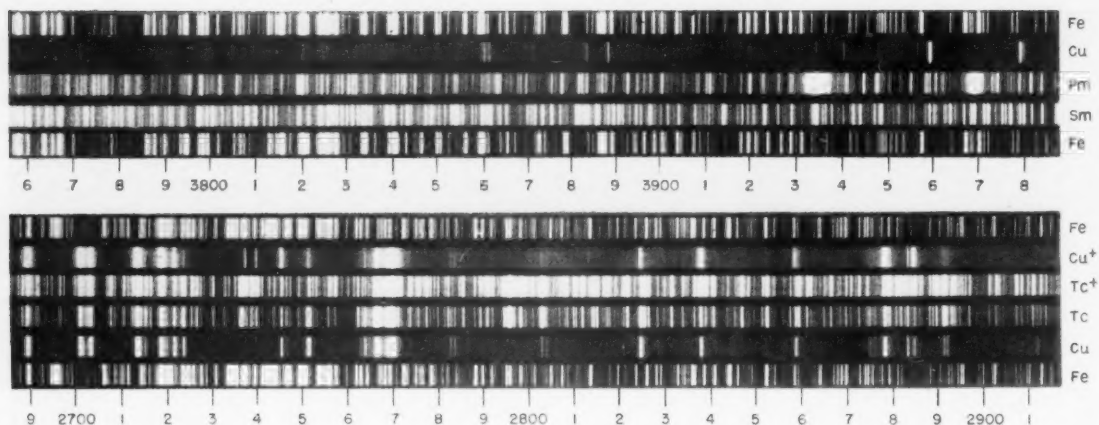
Portions of the spark spectra of promethium and samarium (top) and the arc and spark spectra of technetium (bottom).

weights of neodymium and samarium differed by six units, whereas the average difference in weight of proximate rare earths was only three units.

Many of the chemical and physical properties of these missing elements could be predicted from their positions in the periodic chart of the atoms, and this inspired countless attempts at discovery, most of which were never reported because they ended with negative results. In 1913 the discovery by Moseley of a simple relation between X-ray frequencies and atomic numbers fixed the atomic numbers of the two elusive elements as 43 and 61, respectively, and inspired further efforts to detect them in chemical concentrates from ores. Thus, in 1925 three German scientists published three X-ray wavelengths as proof that they had concentrated and identified element number 43, which they named masurium. This discovery was never repeated or confirmed. Likewise in 1926 X-ray evidence for the discovery of element 61 was reported almost simultaneously by two groups of American scientists and by a pair of Italian chemists. The Americans named it illinium, the Italians florentium. These discoveries also were never later verified.

After the discovery of artificial radioactivity in 1934 it became theoretically possible to manufacture these unseen elements by transmutation of others, and because element 43 was indeed first technically produced in 1937 by neutron bombardment of molybdenum 42 it was named technetium. But the transmutation yield, even with the largest cyclotrons, is very small. With the construction and operation of chain-reacting uranium piles in 1942, an entirely new and vastly more efficient method of making the missing elements became available. When uranium undergoes fission 6.2 percent of the atomic fragments become atomic number 43, and 2.6 percent become atomic number 61. The former, as already stated, is called technetium, and the latter has been named promethium.

In 1949 the National Bureau of Standards received from the Oak Ridge National Laboratory several milligrams of each of these fission products for the purpose

of making reliable descriptions and analyses of the spectra characteristic of these artificial elements. A total of 4 milligrams (0.00013 ounce) of highly pure Tc was used to photograph the arc and spark emission spectra with a large diffraction grating. The spectra were recorded several times from the ultraviolet (2200 A) to the near infrared (9000 A), and between these limits the wavelength and relative intensities of about 2,300 radiations characteristic of Tc atoms and ions were determined. By comparing intensities in arc and spark excitation the lines could be definitely assigned either to neutral Tc atoms or to singly ionized (Tc+) atoms.

Analysis of the data of the first spectrum of Tc shows that in the normal unexcited state Tc atoms (like Mn atoms) have five d-type and two s-type valence electrons. Some 200 lines, representing two-thirds of the total observed intensity, have been explained as transitions between 20 spectral terms belonging to quartet, sextet, and octet systems. A spectral series extrapolated to an ionization limit shows that energy of 7.45 electron volts is required to remove from a Tc atom its last bound electron. (These results will be published in the Journal of Research of the National Bureau of Standards.)

Two milligrams of Tc were reserved for the investigation of the hyperfine structure of certain lines. For this purpose the sample was excited at very low pressure in a hollow cathode cooled with liquid nitrogen to sharpen the lines, and the radiations were examined with interferometers of high resolving power. From the number and spacing of hyperfine components it was found that the nuclei of Tc atoms with 43 protons and 56 neutrons have a mechanical moment of $9/2$ $(h/2\pi)$. (Physical Review **80**, 905 L, 1950.) Furthermore the same Tc atomic nuclei where found to possess a magnetic moment of about 5.2 nuclear magnetons. (Bulletin American Physical Society **26**, 54, 1951.)

Five milligrams of Pm were made available for an investigation of the absorption and emission spectra. The rare-earth character of this sample was immedi-

32

ately disclosed by strong bands in its absorption spectrum and by an extremely complex emission spectrum when excited by electric arcs or sparks. The principal absorption bands were observed to have wavelengths 494.5, 548.5, 568.0, 685.5, and 735.5 millimicrons, in excellent agreement with earlier measurements made by the Oak Ridge National Laboratory on another sample. The arc and spark emission spectra of Pm were recorded photographically with a large diffraction grating, and the wavelengths and intensities of more than 2,200 lines were determined between the ultraviolet (2300 A) and the red (6900 A). Unfortunately, it was not possible with the sources employed to differentiate the spectral lines of neutral and of ionized Pm atoms, and the sample was too highly radioactive to recover for further experiments in the NBS laboratory. Consequently, the preliminary description of the emission spectrum of Pm, although it confirms the discovery of the long-sought rare earth and provides a sensitive test for future identification of Pm, is at present inadequate for structural analysis and derivation of atomic energy levels. These preliminary observations call attention to hyperfine structure of Pm lines, indicating that the nuclei of Pm atoms with 61 protons and 86 neutrons possess mechanical and magnetic moments deserving detailed study.

Although several different isotopes of both Tc and Pm have been made artificially they are all radioactive. The most stable identified isotope of Tc has atomic mass 99 and a half-life of about 500,000 years, whereas for Pm the corresponding quantities are 147 and 3.7 years. The present knowledge concerning nuclear stability

does not definitely deny the existence or possible production in nature of other isotopes of Tc or Pm. Thus, the provisional spectroscopic identification of Tc in the sun seems to require either a longer-lived isotope or possibly the transmutation of Mo.

These considerations have spurred sensitive searches for Tc in terrestrial materials, and will probably lead to similar searches for Pm in natural sources. The new information about chemical and physical properties of artificial Tc and Pm can now be applied to concentration and separation without loss on account of such factors as high volatility and coprecipitation. Finally for positive proof of the presence of these elusive elements there are now reliable data on their uniquely characteristic optical spectra. The strongest lines of neutral Tc atoms have wavelengths, in angstroms, and relative intensities (in parentheses) as follows: 4297.06 (500), 4262.26 (400), 4238.19 (300), 3636.10 (400). Similar data for singly ionized Tc atoms are: 2543.24 (1000), 2610.00 (800), 2647.02 (600), 3237.02 (400), 3212.01 (300), 3195.21 (200). The strongest lines of Pm atoms, probably singly ionized, have wavelengths and intensities as follows: 3998.96 (100), 3957.74 (100), 3919.09 (100), 3910.26 (100), 3892.16 (100). These wavelengths and relative intensities are the most sensitive and critical criteria for the detection of Tc and Pm, respectively, in nature.

NOTE: Arc and spark spectra of technetium by William F. Meggers and Bourdon F. Scribner, J. Research NBS **45**, 476 (1950) RP2161. Absorption and emission spectra of promethium, by William F. Meggers, Bourdon F. Scribner, and W. R. Bozman, J. Research NBS **46**, 85 (1951) RP2179.

Radio-Frequency Micropotentiometer

Extremely simple devices that produce r-f voltages at a very low impedance and at a wide range of frequencies have been conceived and developed by M. C. Selby of the National Bureau of Standards. Known as "R-F Micropotentiometers," they provide accurate voltages from 1 to 10^5 microvolts without the use of attenuators at frequencies up to 300 megacycles and above. Thus, convenient standards of low voltages are made available that should greatly reduce equipment and shielding problems encountered in calibration of present-day commercial voltage generators, attenuators, voltmeters, and other radio-frequency equipment.
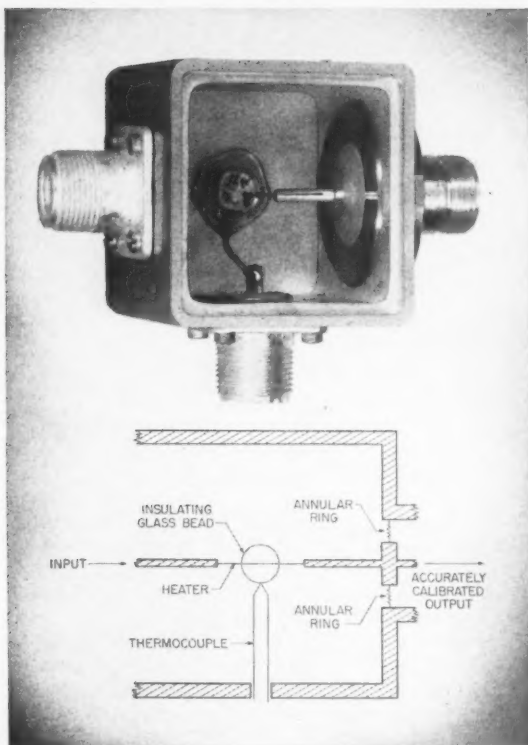
The micropotentiometers should prove especially useful in measurements of radio receiver sensitivity. Here the large disagreement between various standard voltage generators at high frequencies and low voltage levels has been due to three major causes. First, generator output impedance and receiver input impedance are not ordinarily known as functions of changing frequencies. Second, extreme care is necessary in using precision voltage-dropping attenuators. Finally, the long-time calibration stability of vacuum tube voltmeters is uncertain. For these reasons, manufacturers of voltage generators have not been able to

guarantee the accuracy of their equipment at all frequencies. Development of the micropotentiometers now appears to have removed most of the obstacles to standardization of receiver sensitivity.

The new instruments consist essentially of appropriately housed and mounted current-carrying elements, together with means for monitoring the currents they carry. Their electrical constants are simply deter-
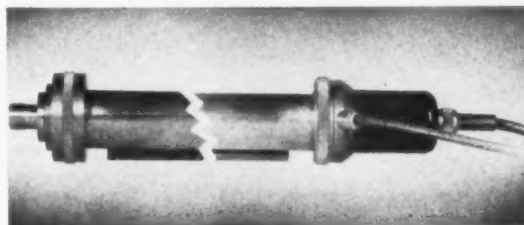
Quarter-wave coaxial-line (1 meter long) terminated on the left by a coaxial-type R-F Micropotentiometer and on the right by a monitoring voltmeter. The micropotentiometer will make available voltages from 1 to 10^5 microvolts at impedances of the order of milliohms and at frequencies up to 1,000 megacycles.

These micropotentiometers are the first low-impedance (of the order of milliohms) devices that provide r-f voltages in the microvolt range and that make these low voltages available without the use of attenuators. They thus provide useful tools for many problems where constant voltage and low voltage sources are required. The devices are inherently frequency insensitive up to and above 300 megacycles. Extremely low and essentially nonreactive output impedance facilitates their use for checks and references with standard voltage generators. They may be used for direct calibration of percentage-modulation indicators. By means of known voltage ratios, the micropotentiometers may be used to extend the range for checking attenuators up to 120 decibels or higher. Simplicity of operation, trouble-free circuitry, flexibility, and absence of serious shielding problems make these instruments particularly adaptable for use by personnel of limited training.

In comparing the micropotentiometers with other sources, such as a voltage-measuring thermistor bridge,* absolute reproducibility and agreement have been limited only by the relative complexity of the standards of comparison. Verification of the exact frequency and voltage ranges of the micropotentiometers in terms of other independent standards is still in progress at the Bureau, along with other phases of design and application. Probably the greatest single difficulty encountered in this work has been the lack of stable sensitive receivers that can indicate 1 microvolt (or lower voltages) at 100 megacycles and higher frequencies with accuracies of 10 percent or better. However, available evidence appears sufficient to recognize in the "R–F Micropotentiometers" reliable, economical, and critically needed instruments for standardization of both single-ended and balanced voltage circuitry.

*For further technical details see, A bolometer bridge for standardizing radio-frequency voltmeters, M. C. Selby and L. F. Behrent, J. Research NBS 44, 15 (1950) RP2055.

mined by using known direct-current voltages and currents. The current-carrying elements are annular membranes, either metallic or nonmetallic, of various radii, thicknesses, and electrical resistivities. Monitoring may be accomplished by means of thermocouples, thermoelements, bolometers, stable vacuum tube voltmeters, or other devices whose indications are independent of frequency. Thermoelements have been used in measurements of 1 to 100,000 microvolts at frequencies from zero to 300 megacycles and also for 100,000-microvolt measurements in the region of 1,000 megacycles.

New Calibration Method for Testing Sieves

A simple, rapid procedure for determination of the effective opening size of testing sieves has been developed by V. R. Deitz and F. G. Carpenter of the National Bureau of Standards. The new method, which employs calibrated glass spheres of graduated size, may be readily applied by anyone familiar with sieving procedures without the need of special apparatus. Use of this technique is expected to reduce markedly the discrepancies that now occur between sieve analyses made at different laboratories with different sieving equipment.

While sieve analyses are widely used in the cement, paint, abrasive, sugar, and other industries for measurement of particle size, the discrepancies in the results of different laboratories—such as those of buyer and seller—often result in rejected shipments and financial loss, as well as considerable ill will. These discrepancies are sometimes due to inadequate sampling procedures, but when good representative samples, or even the same sample, are used, the differences frequently remain. Apparently the greatest source of error in sieve analysis has been the evaluation of the size of the openings of the testing sieves used.

In sieve analysis, the finely divided or granular material is agitated on a sieve of known opening until substantially all the particles that are small enough to pass

the openings have done so. The fineness of the material is expressed by the weights of the various fractions retained by the sieves of different sizes. It has been found that the shaking process can be carried out in a satisfactorily reproducible manner and that the weights of the fractions retained by the sieves can be determined without appreciable error. But measurement of the size of the sieve openings has always presented a problem.

The method now in use consists of the determination of the size of the average opening from microscopic measurements. This requires equipment and technique that many users of sieves do not possess. Moreover, for nonuniform sieves, the size of the average opening has no significance because the largest openings determine the fineness of the material that the sieve will pass.

The method developed at the Bureau, on the other hand, determines the *effective* opening of a sieve, that is, the opening corresponding to the largest size of the calibrated glass spheres that will just pass the sieve. This means that sieve analyses made at different laboratories with different sets of sieves, some of which may not even conform to specifications, can all be reported with reference to the same openings, and the discrepancies that now occur can be greatly reduced.

Evaluation of the effective opening of a sieve with the glass spheres is easily accomplished by sieving a calibrated sample of the spheres in exactly the same manner as in the usual sieve analysis. This sample contains a continuous distribution of sphere sizes. The weight percentage passing the sieve is evaluated, and the effective opening of the sieve can then be read directly from a calibration curve supplied with the sample. Once the effective size of each of a set of sieves is known, all sieve analyses made with the set can be corrected by a simple graphical process to give the same values as a set of standard sieves.

Glass beads of the type used for highway markings have been found a suitable source of glass spheres from 80 to 1,000 microns in diameter (U. S. sieves No. 170 through 18). Separation of the truly spherical beads from the others is accomplished by allowing the beads to fall on a slowly rotating disk set at a slight angle to the horizontal. A gentle blast of air starts the beads rolling, and the spherical ones quickly travel in a fairly straight path to the edge of the disk where they fall into a container. The imperfect spheres and jagged pieces roll more slowly, or not at all, and thus tend to remain on the disk longer. These are carried on with the turning disk and fall into the discard hopper. The jagged pieces are cleared away by a more vigorous blast of air.

Next, the mixture of glass spheres is carefully selected to obtain a continuous distribution of sizes. Individual samples for sieve calibration are then chosen from the master mixture in such a way as to contain the same continuous distribution of sphere sizes.

The calibration of the sphere sizes is obtained by actually measuring the diameters of selected samples of the spheres. The diameters are obtained from their projections on a screen. A total of 14,000 glass sphere diameters are required for each calibration.
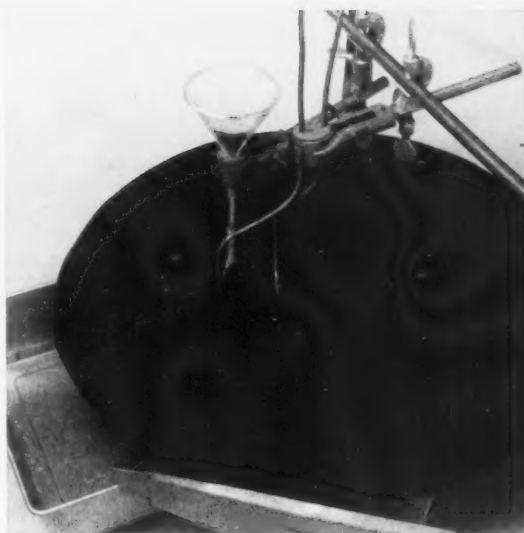
Selection of truly spherical glass beads is accomplished by allowing the beads to fall on a slowly rotating disk set at a slight angle. A gentle blast of air from the metal tube in front of the funnel rolls the round beads toward the container at left. A more vigorous blast of air from the other tube clears away the imperfect beads, which roll more slowly and stay longer on the disk.

The reproducibility in the calibration of the glass spheres has been shown to be about 1 percent of the size of the sieve opening. This is significantly less than the variation—from 2 to 7 percent—allowed in the present specification for testing sieves.

NOTE: For further details, see Methods of sieve analysis with particular reference to bone char, by Frank G. Carpenter and Victor R. Deitz, J. Research NBS **45**, 328 (1950) RP2143. A limited number of the calibrated glass-sphere mixtures are available at a charge of $10.00 each from J. M. Brown, Secretary, Bone Char Research Project, Inc., c/o Revere Sugar Refinery, 333 Medford Street, Charlestown 29, Mass. Purchasers are requested to report their experience in the use of these spheres to Dr. V. R. Deitz, National Bureau of Standards.

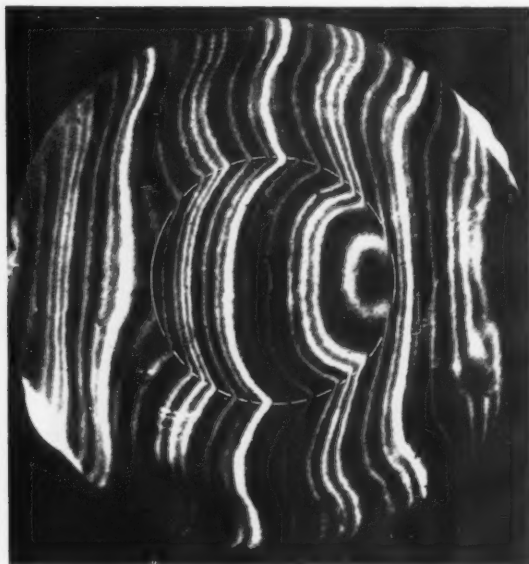# 1901 NBS 1951
Semicentennial Meeting
Calendar

—April—

April 2, American Ceramic Society.
8 to 12, Electrochemical Society.
16 to 18, Union Radio Scientifique Internationale.
19 to 20, ASTM Committee B–1 on Electrical Conductors.
23 to 24, ASTM Committee D–14 on Adhesives.
23 to 25, National Academy of Science.
26 to 28, American Physical Society.
26 to 28, APS Division of High Polymer Physics.

Contour maps of precise optical surfaces, whose contour intervals are a small fraction of a wavelength of light, have been prepared by James B. Saunders in the Optical Instruments Laboratory of this Bureau. By contrast, the usual contour map of a topographic surface may have contour intervals of several feet or more. The optical maps serve the same purpose as topographic maps, except that they reveal ridges and depressions measured in millionths of an inch rather than in feet or inches. For example, optical flats, which are quartz plates for calibrating the precision gages used by science and industry, must be flat within one five-millionth of an inch. Their surfaces must also be parallel to the same tolerance. The new maps can be used for checking the accuracy of these surfaces.
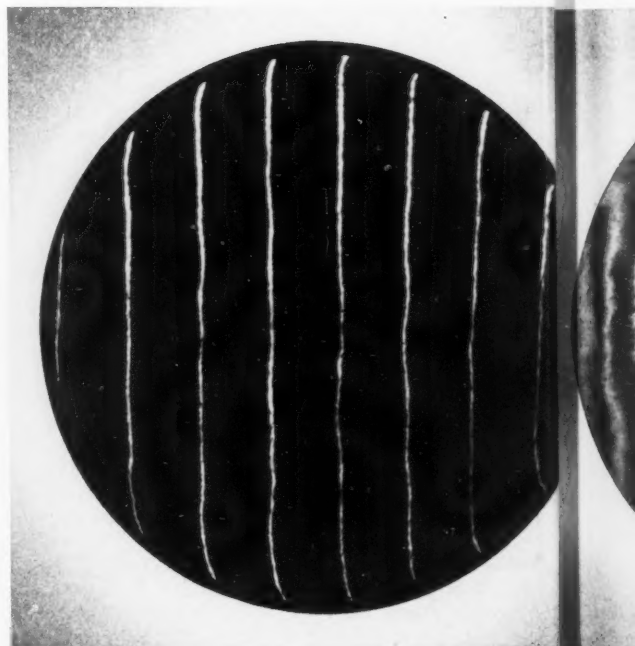
The maps are made by photographing the interference patterns that are formed when light waves are reflected from the surfaces of the specimen and a standard reference of known shape. In itself this is simple interferometry and is common practice in precision measurements of glass optical surfaces. The basic procedure, however, has been modified appreciably in the preparation of the new maps.

The customary procedure is to place the surface that is being analyzed close to and almost parallel with the standard surface, leaving a thin layer of air between. The lines or fringes produced by the interference of monochromatic light reflected normally from these two surfaces then give a good indication of the quality of the surface. When proper adjustments have been made, the fringes are one-half wavelength apart.

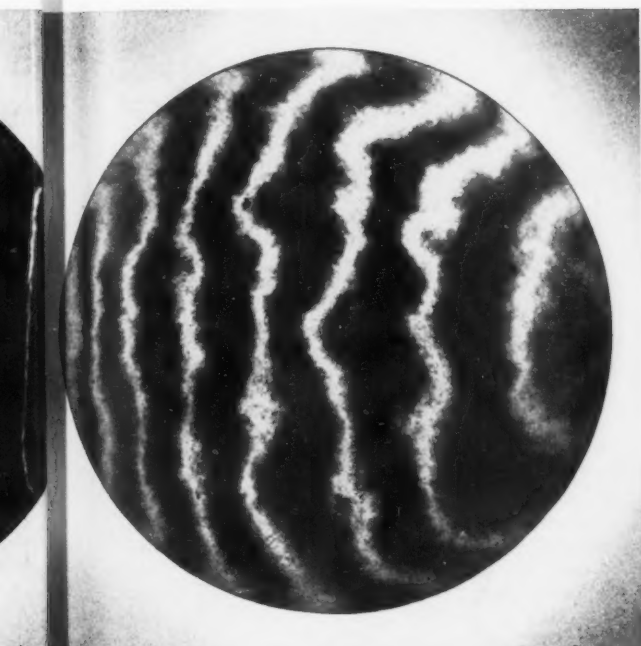Contour maps of precise optical surfaces have been prepa interpo fringes of the usual interferometer pattern. Fringe moves accomp of refraction of the air between the two surfaces, thus cha heir opti flat (separation of lines, one-half wavelength; contour in 0.00001 at the edges, but with other departures from planeness noting $\frac{1}{10}$ v magnified and with 15 lines introduced between each 2 li he origin (Photos awarded second prize in the Fourth Annual AAS graphy-i

Ordinarily these fringes are relatively broad and appear dark against a bright background. Gross irregularities in the surface will cause these lines to bend, and their appearance is a fairly good measure of how smooth the surface is. However, irregularities of several tenths of a wavelength can go undetected if they fall within the area between two adjacent lines. Even smaller irregularities (up to several hundredths of a wavelength) can be completely hidden within the broad dark bands.

Some improvement in the quality of the lines is obtained if both the standard and the unknown are covered with a uniformly thin coat of highly reflecting metal, such as silver or aluminum. This makes the lines thinner. The resulting narrow-line fringes are dark by reflected light or bright against a dark background with transmitted light. With modern methods of metal deposition and with smooth surfaces that are almost parallel to each other, fringes can be obtained whose widths are only one-fiftieth part of their separation. With such narrow fringes, deviations can be measured

Contour map with seven lines interpolated between three one-half-wavelength fringes (bright lines); contour interval, approximately $\frac{1}{16}$ wavelength, or 0.000001 inch. The hill-and-valley pattern reveals a pronounced circular zone arising from the particular stroke and polisher employed in polishing the surface.

...prep interpolating additional fringes between the half-wavelength
...moves accomplished by varying the pressure and therefore the index
...s chatheir optical separation. **Left:** Interference pattern of an optical
...ur in 0.00001 inch), indicates an excellent surface, slightly rounded
...s notling $\frac{1}{10}$ wavelength. **Right:** Portion of the same surface, greatly
...2 lithe original (contour interval $\frac{1}{30}$ wavelength or 0.0000006 inch)
...AAS graphy-in-Science Salon).

amined. When a fringe has moved completely through the half-wavelength interval and reaches the position originally occupied by its neighbor, a double exposure is produced. These heavier, double-exposed lines serve as convenient references to indicate the absolute separation of the plates.

The method that has been used at the Bureau for controlling optical separation of the interferometer plates is to vary the density of the air. This is accomplished by enclosing the plates in an air-tight chamber and changing the pressure in equal increments. The exact amount of each increment can be computed from the wavelength of the monochromatic light, the index of refraction of the gas in the chamber, and the total pressure differential of the system.

For this particular work, the green line of mercury was selected and air was used in the chamber. A constant temperature of $25°C$ was maintained, and the pressure could be varied from 0 to 760 millimeters (1 atmosphere). At this temperature the density of air is directly proportional to the pressure, within a close approximation. Therefore, to divide the space between two half-wavelength lines, for example, into eight equal contour intervals, the necessary pressure change for each additional line was $\frac{1}{8}$ atmosphere, or 95 millimeters.

The apparatus consists of two cylindrical drums that can be bolted together to form a pressure-tight seal. A collimator lens sealed into one cylinder forms the lower window, and a collector lens in the other cylinder forms the upper window of the chamber. A gas line, connected to a manometer through a 2-way stop cock, permits either compression or evacuation of the gas within the chamber. The camera is focused on the interferom-

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to better than $\frac{1}{100}$ wavelength. This still does not reveal surface defects that may appear in the areas between the half-wavelength lines.

A method has now been worked out at the Bureau by which additional lines are placed between each of the half-wavelength lines. As many as 15 have been added in this way, thus reducing the spacing between lines (contour interval) to $\frac{1}{30}$ wavelength, or 6 ten-millionths of an inch. This results in a much more complete map and brings out those details of the surface that are not shown with the wider interval.
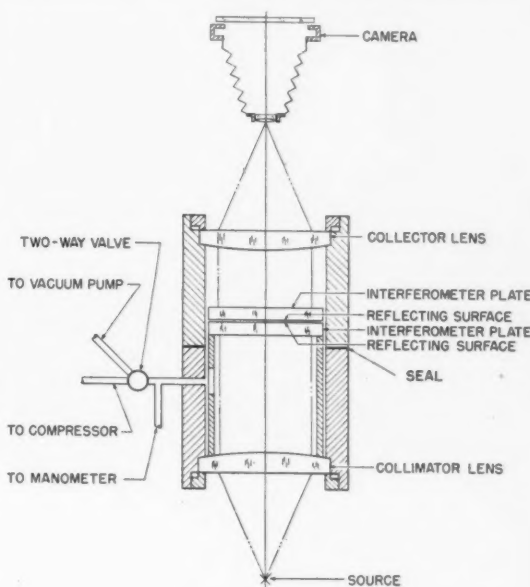
The position of the interference lines can be changed by increasing or decreasing the optical separation of the two surfaces. If this separation is varied in uniform increments and successive exposures are made of the fringes in each of the resulting positions, a series of lines representing equal contour intervals is obtained. By choosing the increment properly, the space between two half-wavelength lines can be exactly divided into any desired number of contour intervals. The result is a complete contour map of the surface being ex-

A special vacuum-tight interferometer was designed for
making the contour maps.

eter plate and photographs the successive positions of the lines as they move across the plate.

A typical map prepared in this way has revealed patterns on the surface of a polished specimen arising from the particular stroke and polisher employed in finishing the surface. Although the conventional half-wavelength photographs showed some irregularities, these could not be correlated to give a complete picture of the shape of the surface. Seven additional fringes,

however, very clearly pointed out the circular character of the pattern. It was then possible to alter the polishing technique in order to obtain a smooth surface. Maps of this type might also reveal other irregularities in a polished surface, such as those caused by small particles of polishing material. The method can therefore be used to control a polished surface to a final accuracy limited only by the number of fringes that can be interpolated between two half-wavelength fringes.

Compressibility Studies on Polymers

Interesting information on the properties of polymers at high pressures—between 1,000 and 10,000 atmospheres—has resulted from compression experiments recently conducted by C. E. Weir of the Bureau with the cooperation of the Carnegie Institution of Washington. Volume-pressure curves have been fitted to the experimental data, providing a convenient basis for comparison of compressibilities.

The high-pressure experiments were carried out as part of a broad program of research now under way at the Bureau on the fundamental properties of high polymers. Polymeric substances—such as rubber, plastics, textiles, leather, and papers—owe their strength, elasticity, and plasticity to the long, chain-like structure of their molecules. The Bureau is investigating the basic constants and properties of these materials in order to learn more about their molecular structure and to interpret their behavior in the form of useful products. While the high-pressure apparatus employed in this work was designed primarily for use in the Bureau's investigation of leather shrinkage, it has been found of value for studying the high-pressure properties of a number of high polymers.

In the experiments at the Bureau, a polymeric specimen was immersed at room temperature in a suitable pressure-transmitting liquid within the smooth bore of a thick-walled bomb of hardened steel. A leak-proof piston was then forced into the bomb, increasing the hydrostatic pressure within and thereby compressing the specimen. At intervals the depth of penetration of the piston and the corresponding hydrostatic pressure were measured. Depth of penetration was determined to 0.0001 inch by means of a dial gage mounted on the ram used to drive the piston into the vessel. Internal hydrostatic pressure was measured with a manganin pressure gage, which makes use of the very small change in the resistance of a coil of manganin wire with pressure. To take into account effects due to compression of the confining liquid, the piston and ram, the packing

washers, and other parts, as well as distortion in the bore of the bomb, a comparison experiment was performed in which the specimen was replaced by a steel bar of similar volume.

For transmission of pressure to the specimen, a liquid was required that would not freeze in the pressure range studied and would maintain fairly low viscosity and electrical conductivity under high pressure. Only a few such liquids are known at present; many that ordinarily have very low viscosity become grease-like under extreme pressure. The use of Varsol for this purpose has thus far limited the materials investigated by the Bureau to those least likely to be affected by immersion in it. Polymeric materials studied include the synthetic plastics polyvinylidene chloride (Saran), polymonochlorotrifluoroethylene (Kel-F), polytetrafluoroethylene (Teflon), polyethylene, and a polyester (Selectron 5003); the raw synthetic oil-resistant rubbers Hycar OR–25, Hycar OR–15, Neoprene, and Thiokol ST; and the natural polymers cellulose and collagen (the principal constituent of leather). Several tanned leathers were also investigated.

Apparatus for studying compressive properties of high polymers. The specimen is immersed in pressure-transmitting liquid within the smooth bore of the hardened-steel, cylindrical bomb (center). Pressure is applied to force a tight-fitting piston into the bomb, thus increasing the hydrostatic pressure and compressing the specimen. The dial gage, mounted on the ram, indicates the penetration of the piston. Connections to a manganin pressure gage, mounted inside the pressure-transmitting liquid, are near the bottom of the cylinder.

In general, the compression observed for all the materials studied fell within a range between the compression values for true solids, which are rather low, and those of true liquids, which are considerably higher. This finding is in agreement with present concepts of the molecular structure of polymeric materials, which are believed to possess a higher degree of order than is found in liquids but less than that of true solids.

It was found that the compression of the specimens could be described within experimental error by means of the equation

$$-\frac{\Delta V}{V_0} = a(P-2000) + b(P-2000)^2 + c(P-2000)^3,$$

in which ΔV is the volume change between 2,000 atmospheres, (the base pressure in these studies) and the pressure P, and V_0 is the volume of the specimen at 1 atmosphere. The values of a, b, and c determined from the experimental data are given in the following tabulation. The similarity in the values of these coefficients emphasizes the close relationship between compressibility and gross molecular structure, which is similar for all materials studied. Apparently small differences in molecular structure have little or no effect on compressibility; this is evident when the values for polyethylene, Neoprene, Thiokol ST, and Selectron 5003 are compared. The agreement between values for Selectron 5003—a brittle material—and the rubbers, which are highly elastic, emphasizes again the fact that

the high elasticity of rubbers results from ease of deformation rather than high compressibility.

The lower compressibilities of cellulose, leather, and Kel-F were to be expected as these materials are somewhat denser at 1 atmosphere than the other polymers. The values given for leather represent an average of the data obtained on vegetable, chrome, and retan leathers as well as on hide collagen and kangaroo-tail tendon, all of which exhibit essentially the same compressibility. It was found that removal of the moisture ordinarily contained by leather (generally about 15% by weight) had little noticeable effect on compression.

Many unexpected polymorphic transitions and freezing points have been encountered in the high-pressure field. One of these, the freezing of water to form ice VI, occurs at 8,710 atmospheres at 20°C with a large decrease in volume. This transition provided a convenient reference point for calibration of the pressure gage used in the Bureau's experiments. In the measurements on the polymeric materials, the only transition observed occurred in Teflon (polytetrafluoroethylene) at 5,500 atmospheres and 25°C and was accompanied by a 2-percent decrease in volume. This abrupt change in compressibility made it impractical to fit the compressibility data for Teflon to an equation of the type given above. Below the transition the compressibility of Teflon is similar to that of Kel-F, while at pressures above the transition it is nearer that of polyethylene.

Second-order transitions, observed as rather marked changes in slope of the volume-pressure curve, have been reported by investigators in other laboratories for some types of rubber in the pressure range studied. All of these rubbers, however, had been vulcanized and generally contained fillers. In the present studies no evidence of second-order transitions in the raw rubbers was found at room temperatures; all compression curves were smooth with the exception of that for Teflon.

NOTE: For further details, see High-pressure apparatus for compressibility studies and its application to measurements in leather and collagen, by C. E. Weir, J. Research NBS **45**, 463 (1950) RP2160; and Compressibility of natural and synthetic high polymers at high pressures, by C. E. Weir, J. Research NBS **46**, (1951) RP2192.

Compressibilities of polymeric materials

Material	Coefficients of pressure terms		
	a	$-b$	c
Polyvinylidene chloride (Saran)	2.17×10^{-3}	19.0×10^{-10}	8.73×10^{-14}
Polymonochlorotrifluoroethylene (Kel-F)	0.99	4.71	0.83
Polyethylene	1.89	14.5	6.10
Polyester (Selectron 5003)	1.76	12.3	4.82
Hycar OR–25 (raw)	2.26	12.3	4.82
Hycar OR–15 (raw)	2.17	20.3	9.42
Neoprene (raw)	2.04	17.5	7.66
Thiokol ST (raw)	1.92	14.1	6.07
Cellulose (dry)	0.92	3.25	0.29
Leather (Collagen and various leather tannages)	1.23	5.60	1.35

Second Conference on High-Frequency Measurements

Over five hundred and fifty of the nation's leading electronic and radio scientists and engineers attended the Second Conference on High-Frequency Measurements held in Washington, D. C., on January 10, 11, and 12, 1951. Jointly sponsored by the American Institute of Electrical Engineers, the Institute of Radio Engineers, and the National Bureau of Standards, the conference presented new developments emerging from laboratories across the nation.

High radio frequencies are playing a growing role

in both civilian and defense activities. The techniques and apparatus discussed during the sessions have important applications to FM and AM radio, television, microwave spectroscopy, frequency and time standards, chemistry, and medicine. The basic importance of measurements in any program related to the national defense revealed in the Conference, places further emphasis on the need for close cooperation between those who design and build high-frequency equipment and those who use it.

The Conference was under the general direction of Prof. Ernst Weber (Microwave Research Institute, Polytechnic Institute of Brooklyn), Chairman of the Joint AIEE-IRE Committee on High-Frequency Measurements. Dr. Harold Lyons (National Bureau of Standards) was Chairman of the Local Arrangements Committee, and Mr. Frank Gaffney (Polytechnic Research and Development Co.), Chairman of the Technical Program Committee.

The technical sessions were divided into four general categories: (1) measurement of frequency and time, (2) impedance, (3) power and attenuation, and (4) transmission and reception. A luncheon session was devoted to a presentation of two scrolls to the National Bureau of Standards by the AIEE and IRE.

Session I: Measurement of Frequency and Time

The first meeting, presided over by F. J. Gaffney, opened with an introductory address by Dr. E. U. Condon on "The impact of high-frequency measurements on research and development." The first paper, "Program for atomic frequency and time standards," presented by H. Lyons (National Bureau of Standards), outlined the NBS program on atomic clocks and oscillators. The program status was outlined for the atomic beam clock, precision spectrograph and spectrum tables, new microwave amplifier, and multiplier tubes. B. F. Husten (National Bureau of Standards) presented a progress report on the improved NBS ammonia clock—a clock that utilizes the absorption line of ammonia to control a quartz crystal oscillator and frequency multiplier chain by means of a servo system.

Stabilization of microwave oscillators with an ammonia absorption line reference was discussed by E. W. Fletcher and S. P. Cooke (Cruft Laboratory). The various causes of instability in any stabilized microwave oscillator, means for improving its stability, and experimental results were presented. L. E. Norton (RCA
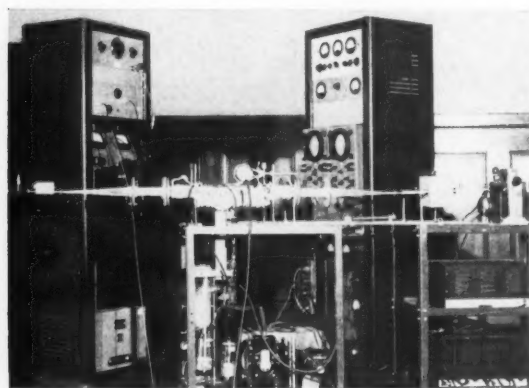
A Stark-modulation type of microwave spectrograph described during the Conference demonstration lectures. The spectrograph is a part of the NBS spectroscopy program, which includes the study of the absorption lines of ammonia gas.
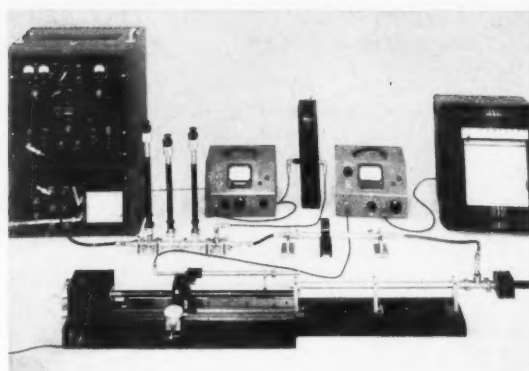
NBS coaxial resonance line (center foreground) used for impedance measurements in the ultra-high frequency range of 300 to 3,000 megacycles. The signal generator, padding, monitoring equipment, and recorder are in the background. This precision line was the subject of a paper at the Conference, and was displayed during the NBS tour.

Laboratories) presented a theoretical analysis of oscillators frequency controlled by gas absorption lines. He described the effect of specific circuits that are used to obtain over-all stability of frequency controlled oscillators. Of particular interest were three specifications; namely, original frequency stability of the uncontrolled oscillator, stability of the standard frequency derived from an absorption line, and a multitude of factors related to comparison circuit-servo control loop elements. In an outline of millimeter wave measurements, Walter Gordy (Duke University) included methods of generating, detecting, and measuring millimeter wave frequencies in the range of 30,000 to 150,000 megacycles.

The past and present performance of low-frequency quartz-crystal resonators and oscillators used in maintaining the national standard of frequency and time interval was summarized by W. D. George (National Bureau of Standards). The improved accuracy of the frequency standard is attributed to recent improvements in uniformity of standard time, greater reliability in temperature control, and better GT crystal units and other components. A new approach to the design of crystal units has resulted in their use as a primary frequency standard in the 3- to 20-megacycle frequency range. This new development, characterized by high Q and low capacitance in the series arm of the equivalent electrical circuit, was reported by A. W. Warner (Bell Telephone Laboratories).

Session II: Measurement of Impedance

R. A. Braden (RCA Laboratories), the presiding officer, introduced N. E. Beverly (Sperry Gyroscope Co.) as the first speaker. Mr. Beverly presented a new method of measuring Q at very high and microwave frequencies. The inflection point of a resonant curve is determined by a null indication and Q obtained only as a function of the frequency at which these null indi-

Award presentation of scrolls to NBS by AIEE and IRE. From left to right: T. G. LeClair, President, AIEE; E. U. Condon, Director, NBS; I. S. Coggeshall, President, IRE, and E. Weber, Chairman, Joint Committee

The American Institute of Electrical Engineers and the Institute of Radio Engineers paid tribute to the National Bureau of Standards, on the occasion of its Fiftieth Anniversary, for its contributions to science and engineering. Awards to the Bureau were presented by the presidents of the two engineering societies at the luncheon ceremony marking the midpoint of the Second Conference on High-Frequency Measurements, in Washington, D. C., Thursday, January 11. Typical accomplishments of the Bureau, which led to its recognition by the Institutes, include initiation and supervision of the atom bomb project during the first 2 years of the program; development of the proximity fuze for nonrotating projectiles, and of the only successfully used guided missile of the last war (the BAT); the atomic clock; research in radio, radio communications, and radio propagation; and development and construction of SEAC (NBS Eastern Automatic Computer) and SWAC (NBS Western Automatic Computer).

Presiding over the awards session, attended by 170 scientists and engineers gathered from all parts of the nation, was Dr. Ernst Weber, Polytechnic Institute of Brooklyn, Chairman of the Joint AIEE-IRE Committee on High-Frequency Measurements. Guests of honor, in addition to the Director of the National Bureau of Standards, Dr. E. U. Condon, and the society Presidents, Le Clair and Coggeshall, included AIEE past-president Everett S. Lee, IRE past president Raymond F. Guy, Dr. Ralph D. Bennett (Director, Naval Ordnance Laboratory), Dr. G. M. Clemence (Director, Nautical Almanac, U. S. N.), and Captain F. R. Furth (Director, Naval Research Laboratory).

cations occur. Broad in application, the method can be used to locate the inflection points of lumped constant circuits, transmission lines, and microwave cavities. A precise sweep frequency method of vector impedance measurement was discussed by D. A. Alsberg (Bell Telephone Laboratories). Recent advances in precise wideband phase and transmission measuring circuits permit practical measurement of the impedance of a two-terminal network by use of the principle that the impedance is defined completely by the insertion loss and phase shift it produces when inserted between known sending and receiving impedances.

As part of a program to develop standards for radio measurements at ultra-high frequencies, H. E. Sorrows (National Bureau of Standards), described a precision coaxial, resonance line for impedance measurements. Sources of error in measurements made with this "Chipman" type line were discussed and methods presented for evaluating the magnitude of those errors that cannot be made negligible by use of proper techniques. A VSWR measuring set was described by S. F. Kaisel (RCA Laboratories) and J. W. Kearney (Airborne Instruments Laboratory), which will present, on an oscilloscope, a quantitative picture of the VSWR looking into a wave guide or coaxial line element over a 2,600- to 4,000-megacycle frequency range. Standing waves of 1.5:1 or greater can easily be measured.

A system for measuring waveguide and coaxial line impedances with a circular waveguide was revealed by A. E. Laemmel (Polytechnic Institute of Brooklyn). The rotary variation of voltage, induced in a pickup loop rotated in a circular waveguide joined to the waveguide or coaxial line containing the unknown impedance, can be used to measure impedance in the same way as is the linear variation of voltage picked up by the probe of a slotted section. Included in a survey of microwave dielectric techniques for small liquid and solid samples by George Birnbaum (National Bureau of Standards) was the theory and application of cavity systems suitable for measuring these properties. The particularly simple equations connecting dielectric constant with resonance frequency and loss factor with Q for such samples suitably located in a TM_{010}-cylindrical cavity or a TE_{10}-rectangular cavity were evaluated.

Session III: Measurement of Power and Attenuation

F. W. Houghton (Bell Telephone Laboratories) presided, and the session was opened by D. M. Kerns (National Bureau of Standards), who discussed absolute microwave power measurements at the Bureau in a paper coauthored with A. C. MacPherson. A dif-

ferential microcalorimeter developed and used for power measurement at the milliwatt level and a summary of measurements consisting largely of cross checks between bolometric and calorimetric methods were presented. A broadband bolometer development for high-frequency power measurements covering the ranges 20 to 1,000 megacycles per second, 1,000 to 4,000 megacycles per second and 4,000 to 10,000 megacycles per second was described by W. E. Waller (Polytechnic Research and Development Co.). All of the units have a VSWR under 1.3 over their specified operating ranges, and low-power and high-power elements, capable of dissipating 1 milliwatt and 100 milliwatts, respectively, have been made to these specifications.

A survey of the progress in measuring current above 100 megacycles was made by H. R. Meahl and Charles C. Allen (General Engineering and Consulting Laboratory, General Electric Co.). The types of vacuum thermocouples available for ultra-high-frequency current measurements were discussed and several methods of calibration reviewed. A cold-cathode, high-voltage, single transient Rogowski oscillograph, given to The Johns Hopkins University by the Aberdeen Proving Grounds, was redesigned to permit the direct observation of frequencies in the 10,000-megacycle range. This modification into a microwave oscillograph, described by W. B. Sell and J. V. Labacqz (Johns Hopkins), was accomplished in two ways; first, by velocity modulating the beam by the E field of a waveguide, then deflecting it through a constant magnetic field; secondly, by using a short lecher wire system for the transmission of the microwave energy.

Precision milli-decibel waveguide attenuation measurement techniques for four-terminal, low-loss microwave structures was presented by J. H. Vogelman (Watson Laboratories). The method is based on the relationship between the attenuation and the resultant standing wave at the input terminal when the structure is terminated in a short circuit. Techniques and equipment were described that minimize the errors due to nonlinearity of detectors, power reflections from the test sample, noise in the detector amplifiers, residual frequency modulation of signal source (long line effects), and attenuation in the measuring line. Termination impedances and corrections on rated values of dissipative type attenuators terminated in any complex impedance were discussed in a paper by Charles M. Allred of the NBS. The derivation, construction, and application of several circle diagrams and nomographs were presented, and experimental data were shown for a wide range of frequencies and impedances.

Session IV: Measurement of Transmission and Reception

E. P. Felch (Bell Telephone Laboratories), presiding at the final session, opened the meeting by introducing J. A. Saxton (Radio Division of the National Physical Laboratory, Teddington, England). Mr. Saxton spoke about a field strength meter designed primarily to study radio wave propagation at 600 megacycles. The meter has a fairly wide band intermediate-frequency amplifier (0.5 megacycle per second centered on 30 megacycles per second) to ensure that a received signal remains in tune during long periods of recording. W. J. Albersheim (Bell Telephone Laboratories) discussed the measuring technique for broad-band long distance radio relays. By rapid scanning, transmission characteristics can be traced on paper strips or cathode ray screens, and alternating switches will permit the superposition of reference traces.

Methods of measuring transmission and impedance of traveling wave tubes operating in the 4,000-megacycle common carrier band in which the frequency is swept over a 500-megacycle band were described by F. E. Radcliffe (Bell Telephone Laboratories). A gain comparator type of transmission measuring set in which moderate oscillator amplitude variations with frequency do not affect the accuracy of measurement was described. A survey of microwave measurement techniques in the 28,000- to 300,000-megacycle region was made by Leonard Swern (Sperry Gyroscope Co.). Emphasis was on techniques fundamentally similar to those effective at lower frequencies. However, new approaches to the microwave measurements problem were discussed; among them, optical and semioptical approaches, and the applicability of molecular resonance absorption.

Recent extensions of crystal-controlled frequencies into the microwave region by harmonic generation, and the extension of the frequency range of crystal units in filter networks, have called for more accurate measurements of the electrical elements of the equivalent network of the crystal unit. Work of this nature being conducted at the Bell Telephone Laboratories was reported by L. F. Koerner. Studies have revealed that the agreement of frequency measurements of a crystal unit in various test circuits is a function of its Q, and the ratio, r, of its shunt capacitance to the capacitance in the series branch of the equivalent network.

The shape of a flat conducting surface has considerable effect on the microwave reflections from it when the source to reflector distance is of the order of magnitude of the dimensions of the reflector. S. J. Raff (Naval Ordnance Laboratory) designed an optimum shape for simulating the reflection back to the source of an infinite plane reflector.

Demonstration Lectures

With E. I. Green (Chairman, IRE group) presiding, this session was devoted to talks that demonstrated the equipment used in the various experiments as well as the results. A Stark-modulation type of microwave spectrograph that displayed the absorption lines of ammonia gas on a projection oscilloscope was exhibited by L. J. Rueger, R. G. Nuckolls, and H. Lyons of the NBS. Of particular note were the possible applications of this technique to chemical analysis, chemical reaction rates, isotope analysis, and nuclear physics.

An instrument that measures and records minute differences in frequency between a test cavity and a reference cavity and used for recording the atmospheric index of refraction at microwave frequencies was exhibited by George Birnbaum, S. J. Kryder, and R. R. Larson of the NBS. Its operating principle and applications for research and industrial control work were briefly described. The output meter of the instrument was projected on a screen, and the variations in meter reading were noted as someone breathed into the test cavity or a moist blotter was held near it.

The 2,600- to 4,000-megacycle VSWR measuring set developed by S. F. Kaisel and J. W. Kearney and disclosed during the second session was displayed. A quantitative picture of the VSWR looking into a waveguide was visually demonstrated on an oscilloscope.

W. E. Kock (Bell Telephone Laboratories) presented the principle demonstration lecture of the evening. A mechanical scanning method for photographically displaying the space patterns of microwaves and centimeter wavelength sound waves was first described and then refraction, diffraction, and focusing of these waves by iterative metallic structures was demonstrated. Photographs of a large variety of field patterns and the simultaneous focusing of sound waves and microwaves by the same lens were also shown.
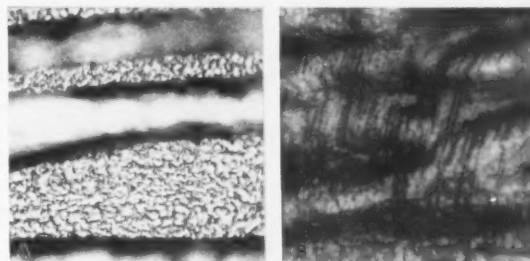
Creep of High-Purity Aluminum

Recent investigations by Wm. D. Jenkins of the Bureau's thermal metallurgy laboratory have led to significant fundamental information on high-purity aluminum—specifically the effects of stress and sudden changes of temperature on creep behavior. The ability of aluminum to produce, with added elements, solid-solution alloys as well as alloys of the precipitation type makes this metal ideally suited as a basis for fundamental studies of the deformation process. Moreover, considerable interest in the behavior of aluminum alloys at elevated temperatures has been stimulated both by the needs of the aircraft industry and by the availability of aluminum and its alloys in a fairly pure state. The Bureau's study included the standard creep tests made in tension at 105°F under constant load conditions. These results were supplemented by data from interrupted tensile tests at room temperature and from other creep tests in which the test temperature was changed from 105° to 95° and back to 105° F.

The extension-time curves for the constant load tests
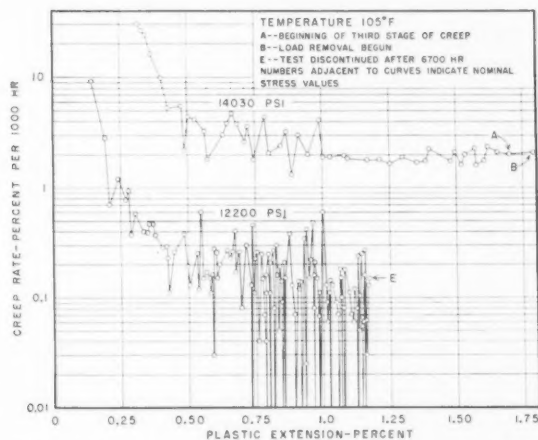
Intragranular structure of a high-purity aluminum specimen tested in tension at 80° F. with a strain rate of 60,000 percent per 1,000 hours. (A) Subcrystallite structure, × 400; (B) slip bands and other strain markings, × 1,100.

conformed generally to the well-known patterns associated with creep: an initial extension upon application of load, a stage of decreasing rate of extension, a stage of minimum rate of extension, and a stage of increasing rate eventually leading to complete fracture. However, as was observed in previous investigations of ingot iron and copper at the Bureau, the rate of change of extension with time in these tests also occurred in a discontinuous manner. The frequency and amplitude of the cycles produced are attributed to the magnitude of the stress and the thermal-mechanical history of the material. Discontinuous flow was also revealed at room temperature by serrated stress-strain curves.

A linear relationship between tensile creep stress and second stage creep rate was not found in the Bureau's investigation. Rather, a sigmoidal curve was produced when these values were plotted on either a log-log or semilog basis. Extrapolations based on a linear relationship could therefore result in serious difficulties.

Several types of recovery (grain softening) were revealed by the different tests conducted during this investigation of high-purity aluminum. One type was manifested by an increase in extension at the beginning of the third stage (the region after which the average creep rate continuously increases) for a specimen tested under constant load at 105° and 95°, then at 105°F. Another type of recovery was illustrated by interrupted tensile tests in which the specimen was deformed to a

Serrated curves are obtained when creep rate is plotted against plastic extension during the course of creep tests of aluminum. Graphic representations of this nature indicate that plastic deformation of aluminum occurs in a discontinuous manner.

predetermined strain, followed by dropping the load to zero. The tensile test was then continued to a higher strain value and the above process was repeated. Lowering of yield stress as a measure of recovery was evidenced in all the latter cases.

Structural features accompanying plastic deformation indicated that the self-recovery process occurring within the individual grains was continuously changing throughout each test. Deformation in different grains was characterized by a difference in the magnitude and distribution of subcrystals and strain markings. Specimens strained at relatively fast rates showed a tendency to fracture in a transcrystalline manner. The cracks that eventually link up to form the main fracture course are initiated in the vicinity of the axis and propagate to the surface. In this way a "rim" is formed whose diameter decreases with increase in strain for any one particular specimen. Increases in creep rate tend to accentuate the formation of the rim.

NOTE: For further technical details, see Creep of high-purity aluminum by Wm. D. Jenkins, NBS J. Research **46** (April 1951) RP2201. Creep of annealed high-purity copper, NBS Tech. News Bulletin **34**, 130 (Sept. 1950) ; Creep of ingot iron, NBS Tech. News Bulletin **34**, 34 (March 1950).

Battery Additives

A new publication recently issued by the National Bureau of Standards contains much information on battery additives that is of interest to the average automobile owner and storage battery user. Various preparations of liquids and solids are being sold to the public as means for rejuvenating worn out or so-called "dead" lead-acid storage batteries. Extensive laboratory and field tests have been conducted by the NBS for the Federal Government in order to determine the practicability of these additives. These tests have shown little or no difference between batteries treated with these mixtures and similar untreated batteries used as control.

This Circular contains descriptions of typical lead-acid storage batteries, and by means of tables and graphs describes different properties of batteries—such as ampere-hour capacity, specific gravity, cell temperature, and water consumption—and the effect of additives on these properties. National Bureau of Standards Circular 504, *Battery Additives*, 30 pages, 15 cents, is available from the Government Printing Office, Washington 25, D. C.

Publications of the National Bureau of Standards

PERIODICALS

Journal of Research of the National Bureau of Standards, volume **46**, number 2, February 1951 (RP2178 to RP2187, incl.)

Technical News Bulletin, volume **35**, number 2, February 1951, 10 cents.

CRPL–D78. Basic Radio Propagation Predictions for May 1951. Three months in advance. Issued February 1951. 10 cents.

RESEARCH PAPERS

Reprints from Journal of Research, volume 46, number 1, January 1951

RP2167. Diaphragm-type micromanometer for use on a mass spectrometer. Vernon H. Dibeler and Fidel Cordero. 10 cents.

RP2168. An electronic circuit for measuring the displacement of pressure-sensitive diaphragms. Maurice L. Greenough and William E. Williams. 10 cents.

RP2169. Heat of polymerization of alpha-methylstyrene from heats of combustion of monomer and four polymer fractions. Donald E. Roberts and Ralph S. Jessup. 10 cents.

RP2170. The McKee worker-consistometer with constant-speed drives. Samuel A. McKee and Hobart S. White. 10 cents.

RP2171. Oxide cathode base metal studies. Ralph Forman and Glenn F. Rouse. 10 cents.

RP2172. Effect of changes in crystalline structure on the infra-red absorption spectrum of cellulose. Florence H. Forziati and John W. Rowen. 10 cents.

RP2173. Analysis of mixtures of olefin hydrocarbons produced by codimerization of butenes. Augustus R. Glasgow, Jr. 10 cents.

RP2174. Surface-area determination by absorption of nitrogen from nitrogen-helium mixtures. William V. Loebenstein and Victor R. Deitz. 10 cents.

RP2175. Transformations to speed the convergence of series. J. Barkley Rosser. 10 cents.

RP2176. Random walks and the eigenvalues of elliptic difference equations. Wolfgang Wasow. 10 cents.

RP2177. Checking and interpolation of functions tabulated at certain irregular logarithmic intervals. Herbert E. Salzer. 10 cents.

CIRCULARS

C504. Battery additives. Paul L. Howard and George W. Vinal. 15 cents.

MISCELLANEOUS PUBLICATIONS

M199. Report of the thirty-fifth national conference on weights and measures. 50 cents.

PUBLICATIONS IN OTHER JOURNALS

Studies on galvanic couples III. Polarization and cathodic protection. H. D. Holler, Jr. Jr. Electrochem. (235 West 102d St., New York 25, N. Y.) **97**, 453 (1950).

Rapid extraction of resins from chilte and guayule rubbers, John W. Wood and Rachel J. Fanning. Rubber Age (250 West 57th St., New York 19, N. Y.) **68**, No. 2, 195 (1950).

Note on Vincent's theorem, A. M. Ostrowski. Annals of Math. (Fine Hall, Princeton University, Princeton, N. J.) **52**, 702 (1950).

Notes on the care and use of electrical instruments. Frank D. Weaver. Instruments (921 Ridge Ave., Pittsburgh 12, Pa.) **23**, 1236 (1950).

Note on the focusing of electron beams in certain magnetic fields, P. A. Sturrock. Proc. Phys. Soc. (1 Lowther Gardens, Prince Consort Rd., London S. W. 7, England) **63**, 954 (1950).

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